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DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN No. 232.

B. T. GALLOWAY, *Chief of Bureau.*

A PRELIMINARY STUDY OF THE FORCED CURING OF LEMONS AS PRACTICED IN CALIFORNIA.

BY

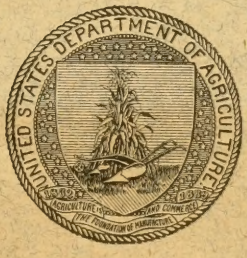
ARTHUR F. SIEVERS, *Chemical Biologist,*

AND

RODNEY H. TRUE,

Physiologist in Charge, Drug-Plant, Poisonous-Plant, Physiological, and Fermentation Investigations.

ISSUED FEBRUARY 13, 1912.



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BUREAU OF PLANT INDUSTRY.

Chief of Bureau, BEVERLY T. GALLOWAY.
Assistant Chief of Bureau, WILLIAM A. TAYLOR.
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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Plant Industry,
Office of the Chief,
Washington, D. C., August 30, 1911.

Sir: I have the honor to transmit herewith and to recommend for publication as Bulletin No. 232 of the series of this Bureau the accompanying manuscript entitled "A Preliminary Study of the Forced Curing of Lemons as Practiced in California," by Mr. Arthur F. Sievers, Chemical Biologist, and Dr. Rodney H. True, Physiologist in Charge of Drug-Plant, Poisonous-Plant, Physiological, and Fermentation Investigations.

The process of hastening the coloring of lemons, known as forced curing or sweating, has a recognized importance among the growers and packers of citrus products, enabling them to place fruit on the market some weeks earlier than they would otherwise be able to do. There has, however, been much dissatisfaction in connection with its use on account of the variability in the results obtained. The study here recorded was undertaken in the hope of ascertaining the effective factors present and of getting them under control. It is believed that this result has been brought measurably nearer and the general direction indicated in which a practical solution of the usual difficulties lies. The investigation made concerns chiefly the process itself rather than the effect of the treatment on the essential qualities of the fruit, but these qualities are in a measure kept in mind. Although this study has pointed out certain fundamental considerations, the present publication does not attempt to apply the results obtained to the practical operations of lemon handling, since more detailed work on certain points is deemed advisable before such an application is made. Nevertheless, in view of the active interest taken by lemon growers and packers in all work pertaining to this subject it is thought desirable to bring out the results already obtained.

Portions of two years have been devoted to this work and valuable assistance has been received from many sources. Chief among the growers to aid us with packing-house facilities and with fruit for experimental handling may be mentioned the Leffingwell Rancho,

of East Whittier, where every facility was placed at our disposal, and the hearty cooperation of the packing-house manager, Mr. L. B. Williams, was of the greatest value. The Whittier Citrus Association, of Whittier, Mr. F. W. Knight being then in charge, also afforded us most helpful cooperation in packing-house experiments. The Arlington Heights Fruit Co., of Riverside, gave us the free use of its groves and packing-house facilities and aided in such other ways as a kindly interest in the success of the work suggested. Other growers and associations also aided us materially, including the Limoneira Co. at Santa Paula and the San Dimas Lemon Association at San Dimas. Laboratory space in the State pathological laboratory at Whittier, Prof. Ralph E. Smith in charge, was generously placed at our disposal during such periods as it was required.

To those mentioned and to many other growers and employees who aided in different ways our obligations are gratefully acknowledged.

Respectfully,

B. T. Galloway,
Chief of Bureau.

Hon. James Wilson,
Secretary of Agriculture.

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A PRELIMINARY STUDY OF THE FORCED CURING OF LEMONS AS PRACTICED IN CALIFORNIA.

INTRODUCTION.

The process of curing is a distinct and very important feature of the lemon industry. The nature of the lemon is such that in order to get it into the condition required by the market it is necessary to pick it while still green and to allow it to continue its further changes while stored in the packing house. This practice is almost universal. There are times, of course, when the fruit is picked in a riper condition, owing to peculiarities of the season which have a tendency to ripen the fruit prematurely, or to the poor condition of the orchards, or in some cases simply to the carelessness of the grower. In an average year the fruit is picked, according to its size, about once every month. The pickers use metal rings of the exact diameter desired, and all lemons which will not slip freely through this ring are picked. A good, healthy lemon when it attains this size is as a rule still dark green in color. If allowed to remain on the tree until ripe such lemons will usually attain a size much too big for the best trade and are therefore undesirable. On the other hand a considerable percentage will ripen before they attain the picking size, in which case they are known as "tree-ripes." This class of fruit is always graded out and kept separate, as it is necessary to handle it quite differently from the green fruit. Being already fully colored and mature, it does not require curing and as a rule is shipped as soon as possible. These tree-ripe lemons constitute, as a whole, an inferior class of fruit, both as to appearance and keeping quality, and are largely consumed in near-by markets.

The term "curing" covers primarily the process which brings about the changing of the deep-green color to the rich, waxy, lemon-yellow. Since the color of the fruit is one of its principal attributes and determines in no small measure the price the fruit will bring on the market, this phase of lemon handling is an extremely important one. The excellence of the color developed depends upon many different factors. The condition of the fruit when picked determines to a considerable extent the success with which the desired color can be developed. Lemons which have begun to turn yellow on

one side or end will as a rule present a poorer appearance when cured than those which were uniformly green. The former have a tendency to develop a dull, brassy yellow, which is undesirable. Although the grade of the fruit is determined by other factors, such as shape, size, and texture, the color is of considerable importance.

Other changes concerning especially the internal properties and characteristics of the lemon take place during curing, which result in producing fruit that may be regarded as ready for market. When picked in the green state the rind consists of the epidermal cells and a rather thick layer of white, spongy material. The thickness of this inner layer varies greatly in individual lemons. Those which have a coarse appearance usually have a thicker layer than smooth lemons. As the ripening process proceeds an apparent increase in the quantity of juice present is seen. This is, of course, an important matter, as the value of the lemon for most purposes depends largely on the quantity of juice available.

This change is accomplished to a large extent through the curing process. Furthermore, when properly cured in the packing house, experience has shown that besides the usual advantages of the tree-ripened fruit the cured lemon has a better appearance, better keeping quality, and a considerably thinner rind.

THE CURING PROCESS.

It is generally believed that lemon curing must be conducted under the greatest possible uniformity of temperature and humidity. Opinions differ somewhat as to the most desirable temperature and percentage of humidity, but it is conceded that there must be as little fluctuation as possible in these factors. The packing houses and curing tents are so constructed as to bring about these conditions. Even in forced curing this uniformity of conditions is regarded as desirable. Figure 1 shows how uniformly the temperature and humidity are maintained in the curing tent and sweat room when compared with the great fluctuations outside.

The curing is conducted mainly in tents in the packing house. These tents consist of rectangular rooms usually of sufficient size to hold about 600 packing cases of loose fruit, or about one carload. The sides and tops of these rooms are of canvas, the sides being lapped over one another at the corners and fastened with cords drawn through hooks. Both ends and sides of the tent can be raised or lowered by means of cords and small pulleys. In this way it is possible to allow air to circulate among the boxes or to shut it out almost entirely.

The fruit, placed loosely in packing cases, is stacked in these tents, usually immediately after it is washed. The outside stacks and the top boxes are sometimes lined with paper to avoid excessive evaporation and the consequent wilting of the fruit liable to take place in these more exposed situations. The tents are arranged side by side in long rows with sufficient open space around each to insure a free circulation of air. When not in use the canvas sides are rolled up, and the floor space can be utilized for other purposes if so desired.

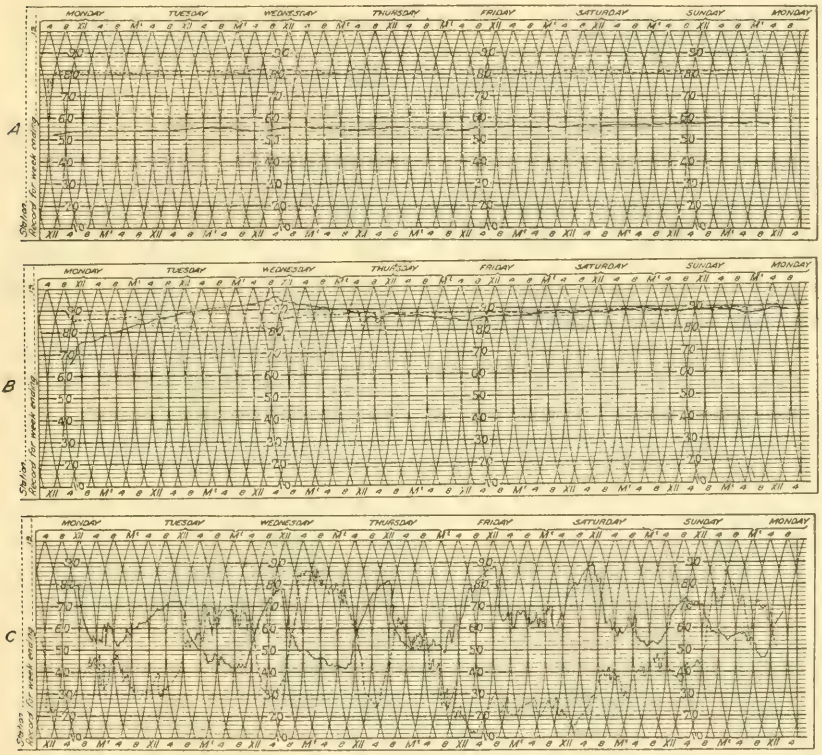

FIG. 1.—Comparison of atmospheric conditions inside and outside of a curing tent and of a sweat room: *A*, Conditions in the curing tent; *B*, conditions in the sweat room; *C*, conditions outside. The solid lines show temperature; the broken lines, humidity.

Green fruit cured under this arrangement requires from 30 to 60 days to reach a marketable condition. The light-green material can frequently be cured in less time than 30 days, especially at certain seasons of the year. The color change from green to yellow takes place very gradually, though not always uniformly, the smooth and lighter colored fruit acquiring the rich lemon-yellow much sooner than the coarse and greener fruit.

The ventilation of the fruit is a matter which requires very thorough study in order to determine just the right amount necessary to obtain the best results. At present it is largely done in a more or less unsystematic way, each man relying upon his own experience with regard to the manipulation of his tents. One must be guided by the condition of the air in the tent, the condition of the fruit, and by external weather conditions. A definite rule as to the proper temperature and humidity which should obtain in the tents has thus far not been laid down. Doubtless no one rule will be practicable for all the conditions met with in the different districts of the citrus region.

THE FORCED CURING PROCESS.

The forced curing process as practiced in the lemon industry differs widely from the ordinary curing process. Briefly stated, it consists in producing the change in color from green to lemon-yellow in a very short time, supposedly by the use of high temperatures and a high percentage of humidity. The object is to secure as nearly as may be the same results as are obtained by the tent-curing system, but in a very much shorter time.

The combination of crop and market conditions operate together in such a way as to make a practice of this kind almost indispensable to the grower who would get the benefit of the fall market, while the consumer is also benefited by the relatively lower prices due to the presence of the forced-cured lemons on the market.

During the summer months the crop as a rule is rather light, and with a fair demand the fruit is almost entirely shipped out. Considerable fruit is kept over in storage from the winter months, but this, too, is disposed of during the summer, so that by fall the packing houses are quite empty and the demands of the markets must be supplied by fruit that is just being picked. The market almost invariably becomes stronger as the season advances, and the desire of the grower to market as much fruit as possible and to market it rapidly is natural. At the same time the fruit when picked is of an intense green color and is in such a condition that from 40 to 60 days would be required to get it into marketable condition by the ordinary curing process. This combination of circumstances has made it necessary to use a method of coloring fruit which makes it possible to rush the crop from the orchard to the car in one or two weeks. During the brisk season, when the demand for the fruit is good, the great bulk of it is no doubt consumed within a very short time after it leaves the car. In other words, the fruit is usually but a short time in the hands of the retailer.

CHARACTERISTICS OF FORCED-CURED LEMONS.

One of the most important questions in connection with this study has to do with the essential characteristics of the fruit produced by the forced process.

If the success of the treatment is judged by the yellow color produced it may be regarded as a satisfactory process, since by careful manipulation it is possible to develop a color which is equal and in some cases superior to that developed by the ordinary curing process.

In using a lemon the thickness of the rind is frequently an important matter to the consumer. If used sliced the lemon with a thick rind is equal or even superior to the fruit with a thin rind, but when used as a source of juice the thinner skinned type has the preference. It would be expected that in the longer process of curing, evaporation of water from the lemon would take place slowly but steadily, with the result that the rind would shrink in thickness and the dimensions of the lemon become reduced. In the sweated lemon the brief time involved and the high degree of humidity maintained would not permit evaporation to take place sufficiently to reduce greatly the thickness of the skin. Consequently the juice can not be as easily squeezed from the sweated as from the cured fruit. In Table I, giving the results of a comparative study of green, cured, and forced-cured lemons, the results of a number of measurements made on fruit from several sources are given. It will be noted that the rind of the green lemons is noticeably thicker than is the case in any of the fruit ready for the market. The results given in the table are based on a limited number of measurements carried out on lemons selected at random from the general run of fruit in the localities mentioned.

Since the chief value of lemons depends on the contents rather than on the exterior of the fruit, a series of determinations having to do with the juice was made, based on a number of representative lemons. The points on which information was sought have chiefly to do with the quantity and acidity of the juice. The average results showing the amount of juice and of acid present are shown in Table I, which follows, each value given being an average of six, except in the summary, which presents general averages covering all determinations of a class. This table shows in a general way how the contents of the fruit are affected by the ordinary curing and the forced curing processes by comparing data with those derived from green fruit, and the outcome of an uninterrupted course of natural ripening is shown in the results obtained with tree-ripe fruit.

TABLE I.—*Thickness of rind, yield of juice, and yield of acid in different types of lemons.*

Type of fruit and locality.	Thickness of rind.	Weight of fruit.	Juice of lemons.				Acid in lemons.	
			Volume.	Specific gravity.	Yield.	Yield of acid.	Weight.	Yield.
	Mm.	*Grams.*	*c. c.*		*Per ct.*	*Per ct.*	*Grams.*	*Per ct.*
Dark green:								
Santa Barbara	6 to 6.5	120.02	37.4	1.0386	32.4	6.82	2.28	1.92
Santa Paula	5.4 to 5.9	132.34	45.4	1.0355	36.6	6.16	2.88	2.13
East Whittier	6.2 to 7.2	120.1	37.7	1.043	32.8	6.33	2.49	2.08
Whittier	6 to 6.4	131.39	40.7	1.0356	32.7	6.16	2.55	1.97
	5.2 to 6	137.24	49.2	1.0361	37.0	5.63	2.74	2.15
	6 to 7	130.5	49.2	1.0378	31.1	5.87	2.37	1.82
	6.3 to 7.1	125.4	40.3	1.0442	33.8	6.52	2.76	2.22
San Dimas	6.3 to 7	143.04	48.8	1.0341	36.5	5.54	2.81	2.03
	5.3 to 6.1	119.0	44.5	1.044	39.5	6.34	2.93	2.50
Riverside	6.2 to 7.2	117.35	38.7	1.0436	34.6	6.35	2.55	2.17
Cured:								
Santa Barbara	6.1 to 7	117.0	39.2	1.037	34.7	7.01	2.84	2.43
Santa Paula	4.2 to 5.6	111.8	45.3	1.039	42.3	6.57	3.10	2.78
East Whittier	5 to 6.3	129.5	47.5	1.034	39.2	6.82	3.36	2.61
Whittier	4.5 to 5.1	119.9	51.5	1.044	44.1	6.94	3.62	3.01
San Dimas	4.2 to 5.1	119.9	52.5	1.042	47.0	6.74	3.51	2.96
Riverside	5 to 6	107.5	41.7	1.043	40.6	6.71	2.91	2.74
Forced cured (sweated):								
Santa Paula	5.2 to 5.7	136.9	56.3	1.034	44.1	6.60	3.83	2.80
	5 to 6	118.9	44.3	1.037	39.7	6.34	2.94	2.54
East Whittier	5 to 5.3	134.4	53.2	1.036	41.1	6.62	3.61	2.71
Whittier	4.3 to 4.8	110.0	46.5	1.031	44.1	6.09	2.92	2.74
	4.7 to 5.3	127.2	48.2	1.034	39.5	6.08	3.04	2.39
	5 to 6	115.2	46.8	1.044	42.9	6.21	3.04	2.60
San Dimas	5.1 to 5.4	114.7	43.5	1.044	39.9	6.46	2.95	2.56
Riverside	4 to 5	99.2	42.0	1.040	44.3	6.47	2.79	2.81
Tree ripes:								
Santa Barbara	4.7 to 5.6	122.6	48.8	1.028	41.2	5.84	2.65	2.20
Santa Paula	4.3 to 5	124.1	48.7	1.033	40.6	5.66	2.84	2.46
East Whittier	4 to 4.4	118.8	49.5	1.031	42.4	5.51	2.79	2.23
Whittier	4.3 to 4.7	121.8	44.2	1.034	41.2	5.75	2.79	2.27
	4.5 to 5.2	102.5	40.0	1.044	41.6	6.45	2.67	2.66
San Dimas	4.4 to 6.1	115.7	42.3	1.037	40.2	5.79	2.34	2.17
Riverside	5 to 5.9	113.3	42.0	1.046	38.8	6.88	3.04	2.68
Summary (average):								
Dark green	5.9 to 6.6	127.63	39.2	1.039	34.7	6.17	2.63	2.09
Cured	5 to 5.9	117.6	46.3	1.040	41.3	6.80	3.22	2.75
Forced cured (sweated)	4.8 to 5.4	119.6	47.6	1.037	41.9	6.36	3.14	2.64
Tree ripes	4.4 to 5.3	116.9	45.1	1.036	40.9	5.98	2.73	2.38

An inspection of the table shows that the rind of the green lemons is markedly thicker than that of cured, sweated, or tree-ripe fruits—the three classes of lemons that are put on the market. The reduction of the rind of the sweated lemons studied seems to have proceeded practically as far as the more slowly cured, tent-stored fruit, although the general opinion prevails that the rind of the sweated lemon is usually thicker than that of the cured lemon. It is possible that in the relatively small number of specimens represented in this table a few unusually thin-skinned sweated fruits may have brought the average measurement lower than normal, but no other evidence to support this supposition is at hand. The greater average weight of the green fruit is probably associated in a large degree with the thickness of the unshrunken skin and the water contained in it. The quantity of juice obtained by the careful use of a conical glass squeezer seems to point toward a greater percentage of juice in all marketable forms of lemons than is obtainable from the green fruit. This appar-

ent increase in juice may represent a real increase due to physiological processes taking place in the fruit after picking. It would take the discussion too far from the subject of this paper to consider here the physiological possibilities involved. Their practical interest is great, however, and further work on this point is desirable. The general conclusion to be pointed out here is the fact that the sweated lemon holds its own with the cured and tree-ripe fruits in both volume and percentage of juice obtainable. The acid content of the juice is a point of very great interest to both the grower and the consumer of lemons. The table shows that the percentage of acidity rises after the lemon is picked, the apparent increase in the case of sweated and cured fruit being due largely, it seems, to the loss of water during these processes. The prevailing opinion among lemon growers that fruit ripened on the tree is less acid than that picked green seems justified by the results here obtained. It seems that the sweated lemon is not greatly inferior to the cured lemon and is better than tree-ripe fruit in the percentage of acidity and the weight of acid present. The inferiority of the naturally ripened fruit in both of these points appears marked.

MODIFICATIONS OF THE SWEATING PROCESS NOW IN USE.

Several methods of sweating lemons are now in use, but their difference lies only in mechanical and technical features, since the object sought and the final results obtained by all are practically the same. The arrangement and construction of the sweat room, according to the prevailing opinion among lemon growers, must be such that the fruit can be subjected to a temperature of about 90° to 95° F. and a relative humidity ranging from 90 to 100 per cent. The main feature in which the sweat houses differ is in the method of supplying these conditions. In discussing these differences the methods of supplying the heat will be considered first.

SOURCES OF HEAT.

Oil stoves.—By far the most common source of heat is the coal-oil stove or so-called distillate burner. These stoves are of different makes, but all are of the ordinary kitchen variety and are made with one, two, or three burners. Asbestos wicks are used, and either ordinary kerosene or distillate is the fuel employed. These stoves differ in their construction mainly as to the minor details, but the newer forms are so constructed as to burn with fairly complete combustion and require less care and attention than the older types. It is necessary, however, that all such oil stoves when used in sweat rooms be carefully watched, for, besides being more or less dangerous, the burners sometimes become clogged with soot, causing the forma-

tion of smoke, which is liable to blacken the fruit. The difference in the burning of these stoves and consequently the nature of the combustion products they yield involve one of the most important points of the whole forced curing process. This will be taken up in detail later.

Gasoline stoves.—The gasoline stoves are used in very much the same way as the oil stoves and are also of the usual kitchen types, gasoline being used as fuel. These stoves are very dangerous, owing to the inflammability of the fuel, and are not used to any great extent.

Gas stoves.—Gas as a fuel is used to a very limited extent in the citrus district. It is burned in low horizontal stoves with large rosette burners. As far as providing the desired temperature is concerned these gas stoves are by far the safest and easiest to handle. There is no filling of oil or gasoline tanks and the heat can be well regulated. In spite of all these advantages, however, the stoves can hardly be called a success, for reasons which will become apparent when the experimental investigations are discussed.

Wood stoves.—These stoves have been given only an experimental trial and are not in general use. The main advantage that can be claimed for them is that they are not at all dangerous. On the other hand, they have the disadvantage of making it necessary to supply a chimney, which in many cases would be inconvenient; in fact, in some places quite impossible.

Steam.—It would seem that by far the best and most economical way of supplying heat would be by the steam system. This would be absolutely safe, since the boiler could be outside and away from the house, and it would be easy to operate. The steam system is in use at present in very few packing houses. It has been tried in a number of places, only to be abandoned after a short trial on the ground that it is ineffective. It has all the advantages mentioned, but has the one important disadvantage—that it will not color the fruit in a way that is satisfactory to the majority of lemon growers. The operation of the system is, of course, extremely simple. The steam is led to the sweat room from a boiler, located outside, and is piped around the wall in 2-inch pipes.

SOURCE OF HUMIDITY.

It is a well-known fact that in order to color fruit successfully a certain amount of humidity is necessary. This is especially true in the sweating process, where high temperature obtains. It has been found that when the fruit is once allowed to wilt it is extremely hard to color, for the green color seems to become fixed in the cells and no amount of sweating will cause it to change. Some of the

humidity required is provided by the fruit itself, for there is more or less transpiration and evaporation of water from the rind, especially at sweat-room temperatures. However, since excessive evaporation will cause almost immediate wilting, it is necessary to supply moisture artificially. This is done in all cases where stoves are used by allowing water to evaporate from pans placed on the stoves. The desired percentage of humidity, which is usually somewhere near saturation, can be obtained by regulating the quantity and temperature of the water.

In the steam-heating system the humidity is usually supplied by means of a small jet of live steam let into the room whenever necessary. In some cases the fruit is actually drenched with water by means of a spray or hose. There is considerable difference of opinion as to the advisability of this practice, some maintaining that water should never be allowed to collect or condense on the fruit.

CONSTRUCTION OF SWEAT ROOMS.

The rooms in which forced curing is conducted are constructed in various ways. In some places the ordinary curing tents are utilized for this purpose. The tents are filled with fruit in the same way as when stored for ordinary curing, except that in the middle of one side space is left for the stoves. Usually double canvas is used in order better to hold in the heat. The corners are carefully lapped over one another, so that the entire tent may be as tight as possible. Even with this arrangement a considerable proportion of the heat escapes, but it has usually been found possible to keep the temperature up to the desired degree. Some attempts have been made to increase the effectiveness of the tents in holding the temperature and humidity by painting the canvas on the inside with a mixture consisting of 3 pounds of paraffin, 1 gallon of gasoline, and 1 gallon of boiled linseed oil, the whole being mixed and applied while hot. The practice of painting the tents is not followed to any great extent, however, possibly because the impression prevails that spontaneous combustion might result therefrom when stored in piles. The principal disadvantage of these tents for sweating purposes is obvious. Since the stoves are located within the same inclosure as the fruit, the latter is subjected to a somewhat higher heat immediately around the fires than in other parts of the inclosure, and the gases and hot air from the stoves are not distributed uniformly, all of which results in uneven coloring. Very careful handling of the stoves may go far toward avoiding this difficulty, but the system is much less adequate and far more inconvenient than the more recent ones and is gradually going into disuse. It possesses certain advantages, however, that are well worth mentioning. During the season when forced curing is not practiced and

all the fruit is stored away to cure, the tents can be used for storing purposes, and there is therefore no loss of floor space. This is of considerable importance, as the majority of packing houses are crowded for room during the spring and early summer. The closely constructed sweat rooms can not well be used for storing fruit, as they do not admit of sufficient ventilation. Another advantage is found in the fact that during the sweating season plenty of tents are empty, and it is possible, when circumstances require it, to conduct the sweating on a very large scale.

Since the sweating of lemons has become a well-established operation most of the packing houses have constructed special rooms for that purpose. The early type of sweat room was built of matched boards, usually with single walls, and of about the same size as the tents. Most of them have a small opening either in the ceiling or at one side to facilitate ventilation and to avoid an undesirably high temperature. These rooms hold the heat much better than the tents and although not air-tight by any means the combustion products from the stoves are fairly well confined in the room. In other respects they work in about the same way as the tents, the stoves being set on the floor with the concomitant disadvantages due to such an arrangement. This form of room is used where the heat is supplied by steam. Through careful observation and study of the results obtained from these rooms it soon became evident that it would be desirable not to have the fires in the same room with the fruit. Since oil and gasoline stoves require much attention it becomes necessary to open the doors at frequent intervals, thus disturbing the uniformity of the temperature. This difficulty was finally removed by introducing the basement sweat room, which in principle is the type in common use today. In this type of sweat room the fires are kept in a cellar under the rooms. The advantages of this arrangement over the old system are manifold. The heat and combustion products of the stoves are forced up through the floor, which in this case is slatted with planks about an inch apart, and are thus diffused throughout the stacks of fruit. The lower boxes may become somewhat warmer than those at the top, but the difference is not very great, as the heated air rises rapidly to the top of the room. Immediately above the fires a piece of sheet iron is nailed to the joists of the floor in order to prevent the fruit directly over the stoves from receiving too much heat. Where a number of such rooms adjoin one another, as is usually the case, the basements generally have communicating doors, or sometimes they all open into a narrow gangway along the side, thus making the entire sweating arrangement a sort of unit plant. In this way the disadvantages of a fluctuating temperature and of smoky and improperly burning stoves due to air currents and drafts from opening

and shutting doors are largely eliminated. By descending into this series of cellars the operator can attend to all the stoves under the different rooms without going through any outside doors.

All the rooms and arrangements for sweating thus far described are located in the interior of the packing houses. As the tight-room-and-basement system grew out of the tent system the construction of sweat rooms inside of the packing house followed as a matter of course. When filling and emptying the rooms considerable time and work are saved by having them as near the grading and sorting rooms as possible, but consideration for other factors has led during the last few years to the building of the entire sweating plant as a unit away from the main house. The advantages gained thereby are highly important and deserve consideration. As is universally recognized, the methods of operating the sweating process subject the packing house to great danger from fire, and as a result the insurance rates are very high, at least during the sweating season. By removing the sweating plant a reasonable distance from the main house the danger from fire is practically eliminated. The sweat rooms themselves are more or less nearly fireproof owing to the considerable quantity of moisture absorbed by the wood, and their removal from immediate contact with the more combustible material in the packing house insures relative safety. As previously stated, these rooms take up considerable space which may be saved by having them outside. There is also the further advantage that it is cheaper and far more convenient to build them according to the latest approved plans when located separately than to attempt to do this inside the general packing house. The advantages here mentioned apply especially to the large packing houses, where several carloads of fruit have to be sweated simultaneously.

As the result of careful observation the lemon men are constantly introducing improvements, and almost every new sweat room is in some respect more serviceable and efficient than the previous ones. The general plan of arrangement and size of rooms, however, is practically the same in all of them, the improvements consisting mainly in the materials from which they are constructed. In giving a detailed description of the various methods of constructing a modern sweating plant with all the latest improvements it must be distinctly understood that the features embodied therein are based on the present system of sweating lemons in California, namely, the application of heat and humidity to the fruit. In the light of the results obtained from experiments as given in the body of this bulletin, a very different construction for this purpose is suggested, all of which will be set forth later.

The lemon grower knows that by using kerosene stoves under his fruit and keeping the room at the desired temperature and humidity

he can color his lemons, and this fact is certain to guide him in constructing his sweat room, as long as the real nature of the sweating is more or less a matter of conjecture. The diagram (fig. 2) shows a cross-sectional view of a modern series of sweat rooms of the isolated basement type. In this plant the basement or cellar is dug out of the solid earth. The side walls are constructed of concrete and the ends of stone. The interior partitions of walls along the gangway are built of a single thickness of matched boards. In several of the newer houses the basement, instead of being dug out, is entirely

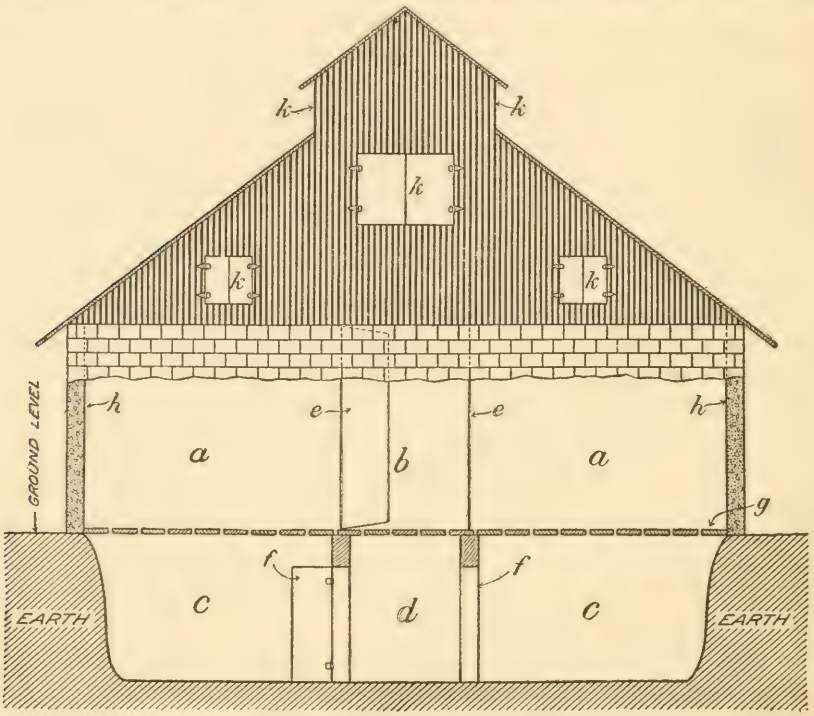

FIG. 2.—Cross section of a series of sweat rooms of the basement type.

above the ground and is set up with concrete. This type of sweat room is more convenient in many places, especially where it is necessary to have the floor level some distance above the ground. In the illustration the floor of the sweat room is very near the ground for the reason that the floor of the adjoining packing house is also very low, it being necessary, of course, that both be at the same level in order to facilitate trucking the fruit to and from the sweat room. Many packing houses, however, are higher above the ground, making it more convenient to build the basement of concrete and to have the floor level at any height desired. In these houses the walls of the main building are built of wood on the concrete foundation, or the

concrete walls of the basement may be extended high enough to form the walls of the rooms as well. These houses have proved very successful. If the partitions separating the several rooms were also constructed of concrete, even better results would probably be obtained. Single wooden walls, as a rule, are not very effective. In one packing house the walls and partitions are constructed of sheet iron and arranged in such a way that they can be taken down and removed during the season when not in use. The sweat rooms in this particular instance are located inside the main house, and, although of very recent construction, the owners are contemplating building a new outside structure.

At first thought it would seem that any sort of construction which would make it possible to hold the fruit at the desired temperature with a reasonable quantity of fuel would serve the purpose of a sweat room, irrespective of the nature of the building material. This, however, seems not to be the case.

CONDITIONS INFLUENCING THE FORCED CURING PROCESS.

The development of the methods in use in sweating lemons has moved along lines which by practical experience have been found to lead to a rapid change in the coloring of the fruit from green to lemon-yellow. The physiological nature of the changes taking place in the fruit as a result of this treatment have not been investigated; hence the basis for a fundamental understanding of the factors involved in the sweating process has never been obtained. The green color of the lemon is due to the presence in the cells constituting the outer layers of the rind of a green coloring matter known as chlorophyll, which probably exists in a condition resembling a solution which impregnates proteid granules, themselves practically colorless. In these layers of cells occur also numerous small, bright yellow masses of microscopic size which are responsible for the yellow color of the lemon. When the fruit is green the greater intensity of the green pigment masks the yellow color present. As changes due to ripening come, with the consequent altering of the chlorophyll to relatively colorless compounds, this green mask is in effect withdrawn, permitting the yellow pigments to give their characteristic color to the fruit. The physiological factors which are involved in the chlorophyll changes as well as the history of the yellow bodies remain for future investigation. In some way not understood, the external conditions supplied in the hastening process bring about in a relatively short time changes which take place slowly when the fruit ripens naturally on the tree or when it is colored in the curing tents.

It has been the purpose of this study to render more clear the relations of the different factors which enter into the successful

operation of the process rather than to undertake to elucidate the physiological problems involved.

As has already been pointed out, the factors which are almost universally regarded as of greatest significance are (1) a proper temperature and (2) a high relative humidity. Some doubts, however, have been entertained concerning the sufficiency of any explanation of this method which takes account solely of these two factors. These doubts have rested on the well-recognized and often striking variation in the time required to color fruit, even when the temperature and humidity factors are strictly controlled. The failure of the steam-heating method seems in itself to point very strongly to the inadequacy of any explanation based solely on the action of heat and moisture. The variability of the fruit, while a recognized factor, seems insufficient to explain the variation in the time required to color it, otherwise steam-heated plants would be expected to succeed as often as others, a supposition not realized in practice.

In undertaking a study of this problem an important lead seems to be found in the fact that when steam-heated plants were abandoned and the old-fashioned, ill-smelling oil stoves were resumed as an emergency measure (a course pursued in a number of packing houses), the fruit was found to color promptly and satisfactorily. The introduction of improved oil stoves, giving complete combustion, with little development of the sharp, pungent odor and disagreeable smell so characteristic of the old type of stove, while again a step forward in the direction of an improved type of mechanical equipment, was followed by less effectiveness in coloring the lemons. Although the improved stoves gave the required heat and the humidity was readily supplied, the effectiveness of the apparatus was much lower than in the case of the less carefully constructed stoves of the earlier type. The chief difference lay in the fact that in the latter type the poor admission of air caused the stoves to burn with incomplete combustion, thereby giving rise to products which imparted to the atmosphere such an intensely sharp and pungent odor as to make it almost impossible for anyone to stay in the rooms for more than a few minutes at a time. These stoves, which needed much attention because of the imperfect feeding, had a great tendency to burn unevenly and to smoke.

As a result of this and similar experiences the impression soon gained ground that there must be some important relation between the coloring of the fruit and the nature of the atmosphere produced by the stoves, since in this latter respect was found apparently the only feature in which the two kinds of stoves differ. In other words, some other factor besides heat and humidity has a strong influence in coloring lemons. If this assumption were correct, many of the difficulties

met with in the sweating process could be explained. For instance, it was found that in those rooms in which the fruit was always slow in coloring the stoves produced an atmosphere much less pungent than usual, owing possibly to some peculiarity in the construction of the room itself which might cause unusual air currents. The failure of the steam-heating system could also readily be explained, because in this system no combustion products of any kind are present. It had also been repeatedly observed that hot weather is a serious drawback to rapid sweating. During the early part of the sweating season the outside temperature is often 90° F. or more, and consequently at this time of the year the natural temperature in a tent or room full of fruit is very nearly as high as it is usually kept for sweating purposes. It is impossible, therefore, to use stoves for any length of time without forcing the temperature too high. In such cases the fruit will take many days longer to color than during colder weather when the fires can be kept going continually. If it were merely a question of temperature, it could hardly make any difference in the effect whether such temperature were supplied by natural or by artificial means. Furthermore, the advantages of a tight room over the ordinary tent for sweating purposes would lie not so much in the facility with which the temperature could be kept up as in the closer confinement of the atmosphere surrounding the fruit.

It will be seen, therefore, that opinions concerning the sweating process were in a state of uncertainty when the study of the subject was taken up in the fall of 1907. At that time there were comparatively few advocates of the theory that some unknown factor, in some way connected with the stoves, had an important bearing on the success of the operation. That there was much evidence pointing that way was quite generally admitted, but the old idea that heat and humidity were the two chief factors upon which the process depended was still firmly fixed. Even those who recognized the possibility of some other factor considered it of minor importance or as dependent for its effect upon the individual or combined action of heat and humidity.

EXPERIMENTAL WORK.

EXPERIMENTS WITH CARBON DIOXID.

In the summer and fall of 1907 some experimental work was begun at Whittier, Cal., by Mr. L. B. Williams, of the Leffingwell Rancho, regarding the effect of the gaseous products of the sweat rooms on the coloring of lemons. This work was confined entirely to carbon dioxid, one of the main constituents present in the sweat rooms, resulting from the use of the stoves and from the respiration of the

fruit. Preliminary experiments were conducted on a small scale, the carbon dioxid, at both ordinary and sweat-room temperatures, being conducted from a cylinder into small wooden boxes containing the green fruit. The results appeared to indicate a decidedly beneficial action from the gas, and the experiment was repeated on a larger scale. A room large enough to hold about 500 packing cases of fruit and constructed in such a way as to be very nearly air-tight was filled with green fruit, and the carbon dioxid, in quantity sufficient to put out a candle placed in a small alcove window about 4 feet from the floor of the room, was allowed to pass in. This experiment was conducted as nearly as possible like those in the small wooden boxes, but the result was an utter failure, as the fruit, when taken out after about two weeks, showed no advance in color. It was then placed in a tent and under curing conditions colored up fairly rapidly.

The experiment was tried again a little later, but the operator took care to use a weaker concentration of the gas. The door was thrown open approximately every 24 hours and the room ventilated, after which fresh gas was allowed to pass in. This lot of fruit colored fairly well in about two weeks, but, taken as a whole, the results obtained could hardly be considered as evidence that the carbon dioxid had a very decided effect on the coloring of the lemons. Some benefit was derived from its use, but not to an extent that would account for the action of the sweat rooms.

It was at this time that the writers were invited to attempt a series of experiments on this problem in cooperation with Mr. Williams at the Leffingwell Rancho. In view of the rather indefinite results obtained in the experiments just described and in view also of the lack of any conclusive evidence concerning the operation of the factors involved in the sweat-room practice, it was deemed best to devote all efforts at first toward establishing the actual effects, if there were any, of the sweat-room atmosphere on the coloring of the fruit. Owing to some unusual conditions during the winter and spring of 1909, the fruit was very yellow in the orchards and no really green fruit could be obtained in any quantity. It was necessary, therefore, to postpone further operations until the following September.

APPLICATION OF GASEOUS PRODUCTS, WITH THE ELIMINATION OF HIGH TEMPERATURE AND HUMIDITY.

In planning the experiments it was decided to work along two lines: (1) To subject the fruit to the action of gases generated by the poorer type of oil stove and eliminate the temperature and humidity factors; (2) as a check, to subject the fruit to sweat-room temperature and humidity and eliminate the gases.

Two boxes large enough to hold about three packing cases of lemons were secured for use in the experiment. One box (designated as box 1) was of wood, very tightly constructed and lined with several layers of newspaper to insure against any excessive leakage of air. The cover rested on a strip of felt and was so arranged that it could be clamped down very tight. This box was not air-tight, but as no pressure was to be used it was considered sufficiently tight to provide against any considerable leakage. The other box (designated as box 2) was of galvanized iron, having a cover provided with a vertical edge about 3 inches wide which dipped down into a trough about an inch wide and 3 inches deep around the top edge of the box. This trough was filled with water, thus preventing any considerable passage of air either into or out of the box.

To transfer the gases from the sweat room to these boxes a small air compressor was used. This compressor was mounted on the roof of the sweat room, the intake pipe being extended down into the sweat room about 3 or 4 feet. The pipe was prolonged by means of a stout rubber hose, which extended about 20 feet to the boxes, to both of which it was connected by a T-shaped arrangement. The pump was driven by a small electric motor. The machinery was first tested in a preliminary way to find out, if possible, whether the physical qualities of the gases were affected by their passage through the pump. The pump was not working under compression, and no considerable heat was generated in the water-cooled cylinder. It was necessary to keep the plunger oiled, and consequently the gases as they passed through the pump came in contact with this oil, some of which was carried through the entire length of hose. It was found, however, that as they came out of the end of the hose these gases possessed the same characteristic odor they had in the sweat room. As the odor is one of the chief characteristics, this fact was deemed sufficient evidence that no radical change had been effected in the gases while being forced through the pump. It was also found that while passing through the 20 feet of hose the temperature had been lowered from about 92° F. (the temperature of the sweat room) to about 70° F. The humidity of the sweat room was kept at a point approaching saturation. A considerable quantity of this moisture was carried over with the gases, some of it being condensed, owing to the drop in temperature, and was ejected at the end of the hose in the form of water. The gas was pumped into both boxes simultaneously, being passed into one end near the bottom and allowed to pass out through a small exit near the top at the other end, thus insuring a continuous circulation of the gases around the fruit.

Experiment 1.

It was the object of the first experiment to subject the fruit to the action of the gases at normal outside temperature. For this purpose box 1 was used. In box 2, which served as a check, the fruit was subjected to the gases under the same conditions as in box 1, except that a temperature similar to that in the sweat room was maintained. This was accomplished by placing a small kerosene stove under one end of the box and applying the heat in such a manner as to keep the temperature at or near 90° F. A third box (box 3), which resembled box 1 in construction, was placed on the top of a vacant sweat room directly across the passageway from the room containing the other two boxes. A 6-inch galvanized-iron pipe was then extended from the basement of the operating sweat room vertically to a level with the top of the room and then run at right angles across the passageway and into the wooden box. A small 2-inch pipe was provided as an exit from the box through the ceiling of the room below, so that the gases would move by natural draft from the cellar of the operating sweat room, where they were being generated, into the box and thence into the empty room below. The reason for the arrangement of this box was twofold. It was desired to determine whether the gases could be conveniently conducted from one room to another through natural draft without disturbing their effectiveness, and whether a slow circulation of the gases through the fruit had the same effect as the rapid forced passage in boxes 1 and 2.

The fruit that was used was taken directly from the washer, the entire lot being uniform, so that all three boxes were filled with fruit as nearly alike as it was possible to obtain. It was quite uniformly dark green in color and not excessively rough. The regular sweat room was also filled with fruit from the same lot.[1] The fruit was kept in contact with the gases day and night until the proper color had been acquired. This was accomplished in five and one-half days. At this point the large majority of the fruit was of a uniform yellow color. Some of the very rough material was still too green for shipment, as is the case in all sweating operations, but the process had reached a stage at which the fruit is ordinarily taken out of the sweat room. In order to get a definite idea of the comparative results obtained in the three boxes, the fruit was turned over to the regular graders, who were instructed to grade it into two lots, the yellow, marketable lot and the green lot. The lemons in each lot were counted and the percentage calculated. The following tabulation shows the results:

[1] Several rows of fruit from a previous lot were already in the sweat room. The remaining space was filled with the new picking.

TABLE II.—*Results of treating lemons with gaseous products, with and without heat.*

Box No.	Condition.	Number of lemons.			Per cent of lemons.	
		Total.	Colored.	Not colored.	Colored.	Not colored.
1	Gases, no heat (forced draft)	508	464	44	91.3	8.7
2	Gases and heat (forced draft)	403	326	77	80.9	19.1
3	Gases, no heat (natural draft)	324	301	23	92.9	7.3

It should be stated here that, in grading fruit for shipment, color is not the only point considered. Size, shape, and texture are probably equally important in determining the different grades. The fruit used in this experiment was all taken from the same lot and would consequently grade very nearly alike as far as choice

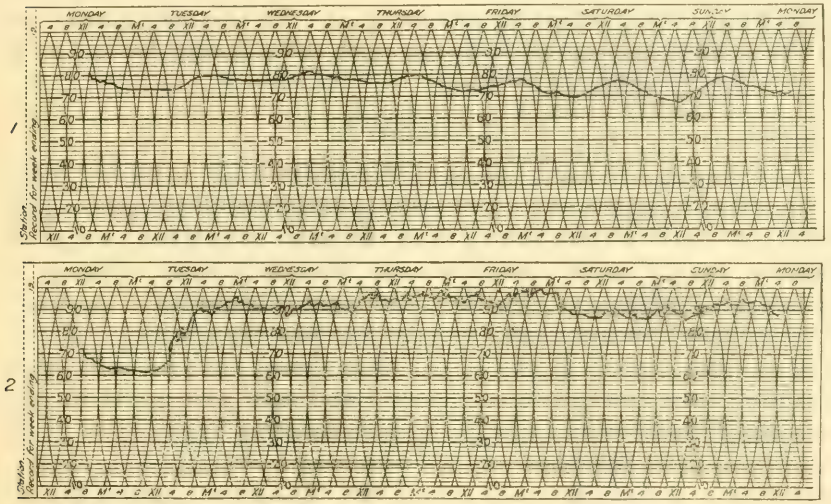

FIG. 3.—Record of temperature in boxes 1 and 2 during experiment 1.

and standard grades are concerned. Therefore, the only factor necessary to consider in this lot was the color.

In studying the foregoing tabulation, it is found that in both boxes where the gases were applied without heat the percentage of insufficiently colored fruit was very small when the fact is taken into consideration that it was very dark green to begin with. In box 2, where the fruit was kept at a temperature similar to that in the sweat room, the coloring was not so perfect. This must not be taken to mean that the heat was necessarily a hindrance. The explanation may lie in the fact that possibly the distribution of the gases through the two boxes was not exactly the same. The fruit which was put in the regular sweat room to serve as a check was taken out a few hours previous to that in the boxes. The charts in figure 3

show graphically the temperatures that prevailed in boxes 1 and 2 while the experiment was in progress. No record was obtained in box 3, but thermometers indicated that the temperature was very similar to that in box 1. The humidity in boxes 1 and 2 was very high. Much water vapor was carried over by the gases and this condensed in the boxes. Judging from appearance, the humidity was about the same as in the sweat room.

The results brought out by this experiment are highly significant. The object of the sweat room was here accomplished by means of the gaseous products in the same time and with as much success as in the sweat room itself.

Experiment 2.

The second experiment was a duplicate of the first. The fruit used was of the same intensity of green, but slightly rougher, and the desired color was obtained in one week. In this experiment the fruit in the three boxes colored very much alike, though boxes 1 and 2 developed a slightly softer color.

Experiment 3.

In experiment 3 the application of artificial heat under box 2 was discontinued, both boxes 1 and 2 being subjected to the gases alone. Box 3 was also discontinued. A modification was introduced, however, in regard to the humidity. In the previous experiments no attempts were made to regulate the amount of moisture in the boxes. The humidity in the regular sweat room was always very high, the sides of the room and the boxes often being covered with water resulting from condensation. Several attempts were made to keep records of the humidity by placing self-recording hygrographs in the room, but these machines refused to record accurately in an atmosphere so heavily laden with moisture. The few records obtained indicated that the air in the room was very nearly or entirely saturated. As has been stated previously, this moisture was largely carried over with the gases through the pump; consequently the condition of the atmosphere in the experiment boxes as regards humidity was very similar to that in the sweat room. The fruit was often covered with drops of water and the sides and bottoms of the boxes were very wet.

Inasmuch as the heat had failed to show any beneficial influence in box 2, it was deemed advisable to determine whether the humidity had any marked effect on the coloring of the lemons when used in the absence of heat. To show the effect of this humidity, box 1 was equipped with an arrangement by which the fruit and interior of the box could be kept dry. This was done by placing a tall, narrow, earthenware crock in one end of the box filled with about 5 inches of

strong sulphuric acid. The crock was provided with an earthenware cover having a hole in the center 1½ inches in diameter. The pipe carrying the gases from the pump was then extended through the top of the box and the end inserted into the crock through the small hole in the cover. This pipe was about five eighths of an inch in diameter, thus allowing considerable space for the air to pass out around it through the hole in the cover. The end of the pipe was extended some distance into the crock, so that the gases, as they were forced through the pipe by the pump, played upon the acid and then circulated up through the cover and thence through the fruit. It was hoped that by this arrangement the acid would absorb sufficient moisture from the gases to prevent the humidity in the box from exceeding that usually present in the curing tents. The fruit used was similar in every respect to that used in experiment 1, and after seven days it was sufficiently colored to be graded, though a small percentage of the very rough material was still somewhat green. It was found that the acid had effectually reduced the humidity in box 1 to a point where the fruit resembled that under tent conditions, both as to appearance and touch. There was no condensed water on the fruit or on the sides of the box, and the paper lining which had hitherto been soaked with water was now quite dry.

The conditions in box 2 were the same as before. Much condensed water had collected on the fruit and almost an inch of water had accumulated in the bottom of the box. To show the amount of moisture which had been taken up by the acid it may be mentioned that the tall crock was very nearly full of water after the seven days' treatment. The difference in the humidity of the two boxes, therefore, was considerable—as great, it is believed, as that between the sweat room and tent conditions—yet no appreciable difference was seen in the color of the fruit. Furthermore, the fruit was colored in seven days.

These results clearly indicate that high humidity is not an essential factor in the coloring of lemons. This must not be understood to mean that moisture can be dispensed with entirely, since, as has been pointed out elsewhere, a certain amount of it is necessary in order to keep the fruit from wilting. The degree of humidity necessary for this purpose, however, is from 20 to 25 per cent less than that usually present in the sweat rooms. Figure 4 shows the record of temperature in the two boxes during the experiment.

Experiment 4.

Experiment 4 was an exact duplicate of experiment 3, so far as it concerned the treatment of the fruit. The fruit used, however, was noticeably darker in color. After 10 days it was ready for grading, although from box 1, in which the humidity was kept low, the fruit

could have been taken out a day earlier than from box 2. The cause of this slight difference was not apparent, but was probably due to an unequal distribution of the gases. These results again indicate that high humidity exerts no influence on the coloring of lemons. It has been the experience of lemon men that when the fruit is kept in the sweat room after the desired color is acquired there is a tendency to develop a poorer, "brassy" yellow. In other words, the process seems to go too far and the fine, soft, waxy yellow color is injured. This is known as overcoloring and is very liable to happen to light-green fruit when it is placed in the same room with dark-green fruit and handled under the same conditions, unless it is carefully watched. In experiment 4 an interesting point was brought out in this connec-

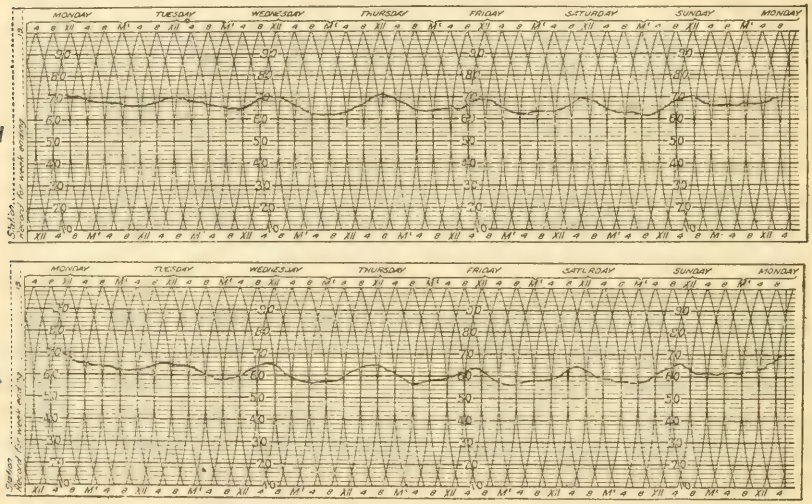

FIG. 4.—Record of temperature in boxes 1 and 2 during experiment 3.

tion. A small lot of light-green fruit was placed in box 1 with the dark-green material. Upon examining the lemons in this box on the sixth day it was found that the light-green fruit was fully colored. It was left in for further treatment until the experiment was completed four days later by the coloring up of the dark-green fruit, but these additional four days seem to have had no effect on the fruit already colored, for the color was perfect in every respect.

EXPERIMENT 5.

The conditions of experiment 5 duplicated those of experiment 4, dark-green fruit being used. Nine days were required to produce the desired color, and a slightly better color was developed in box 1.

Experiments 3, 4, and 5 served to bring out some facts concerning another very important problem of the forced curing process, namely, the loss of the stems, which subject will be taken up later.

APPLICATION OF HIGH HEAT AND HUMIDITY, WITH THE ELIMINATION OF GASEOUS PRODUCTS.

The experiments, which have just been described, were based upon the application of the gases from the sweat room in the absence of high heat and humidity, and it has been shown that lemons can be successfully colored under such conditions. The experiments now to be considered are exactly the reverse, namely, the application of high heat and humidity without the gases from the sweat room.

Experiment 6.

In experiment 6 a galvanized-iron box of the same size and construction as box 2 used in the previous experiments was filled with dark-green fruit. In order to exclude the outside air and gases from the box a water trough was constructed around the top of the box into which the edge of the cover dipped, making an effective water seal. This box was placed in a sweat room heated in the usual way by means of stoves in order to secure a sweat-room temperature in the box. Before the box was closed the fruit was sprinkled with water in order to insure sufficient moisture. A check was provided by placing in the sweat room two boxes containing lemons similar to those placed in the iron box and exposing these freely to the conditions prevailing in the sweat room. This check fruit was colored in six days, at which time the experimental box was opened. By means of thermometers it was known that the temperature in the experimental box had been maintained steadily between 92° and 96° F. Much water had condensed on the fruit and a considerable quantity had collected on the bottom of the box. It was plain, therefore, that so far as heat and humidity were concerned, the fruit had been subjected to the same conditions as the check. However, the fruit was as green as when it was put in. The box was taken away from the sweat room and thoroughly aired for several hours. About a third of the fruit was taken out and placed in the room as a check on what was left in the box. The box was then closed and replaced in the sweat room. Every few days it was taken out of the sweat room and ventilated, as a rather sweetish odor developed if it remained closed too long. Aside from these few intervals when it was being ventilated the fruit was constantly in a temperature of about 92° and in a saturated atmosphere. The check fruit which was placed in the sweat room after having been in the box for six days colored rapidly. This seemed to indicate that although the fruit had apparently made no progress in the box, some action had taken place which caused a rapid coloring as soon as it was exposed to the atmosphere of the room. The fruit in this box was kept under the above treatment for 18 days, after which it was taken out and

placed in a tent. It had not changed in color and resembled in every way fruit which had just come from the washer. After being placed in the tent it colored fairly rapidly.

Experiment 7.

In experiment 7 the same general plan was followed as in the preceding. To insure somewhat better facilities for ventilation, however, the box when placed in the sweat room was connected with the outside air by means of a half-inch rubber hose. This hose led through the wall of the sweat room into the side of the box, and another similar hose extended from the top of the box through the wall of the room to the outside. By this means a limited circulation of fresh air was obtained, which tended to some extent to keep the atmosphere in the box fresher. In addition to this the box was opened and thoroughly ventilated every five or six days. The temperature and humidity were kept the same as in the previous experiment. The fruit was kept 24 days under this treatment without any noticeable change of color.

These two experiments show the slight influence of heat and humidity in coloring lemons in the absence of any combustion products. It must be stated, however, that the rather close confinement of the fruit in the box may possibly in some way have interfered with the process of coloring. The fact that the fruit made less progress during the time it was under treatment than would have been the case in the same length of time in a tent or in a steam-heated sweat room would strongly indicate that a lack of sufficient ventilation may have been an influential factor in the experiment. However, the best constructed sweat rooms, especially those having concrete walls, are so nearly air-tight that when entirely filled with fruit and kept at sweat-room temperature and humidity they allow of very little ventilation. The fruit in this experimental box filled only about half the space, thus leaving an air space which was probably larger in proportion to the quantity of fruit than usually exists in a sweat room.

Taken as a whole, the experiments strongly indicated that by the application of heat and moisture alone the coloring of lemons was effected only very slowly, if at all.

Piping gaseous products to distant rooms.

In view of the fact that the experiments with regard to the action of gaseous combustion products on the coloring of lemons had thus far been conducted only in a small way, it was deemed desirable to experiment on a larger scale, making use of the facts already learned. In the work with box 3 in the early experiments, it had

been found that with a proper system of pipes the gaseous products of the sweat room could be conducted to neighboring rooms by natural draft, and this scheme was therefore adopted.

Experiment 8.

In experiment 8 a 6-inch galvanized-iron pipe was extended from the basement of the operating sweat room to an air-tight fumigating room about 40 feet away. This room was large enough to hold about 500 packing cases of fruit. In order to create a slight draft a small opening was made at the threshold of the room, and it was found that the room filled very rapidly with the peculiar odorous gases from the sweat room. As the pipe carrying the gases passed through the open air for a distance of about 40 feet, the gases when they entered the room had been cooled to the temperature of the air outside. A large amount of moisture was carried over, partly in the form of vapor and partly as condensed water. Unfortunately, the market demand for fruit at this time was so great that it was impossible to secure enough green fruit to fill the room and a few boxes, therefore, had to suffice. This fruit was colored in 10 days.

Experiment 9.

In experiment 9 very dark green fruit was used, and the experiment was conducted in a manner similar to experiment 8. One box was covered with paper, while two were left open. The fruit was taken out in two weeks, and that in the paper-covered box was well colored, while the other two boxes contained some slightly green fruit, mainly that which was quite rough.

Experiment 10.

In experiment 10 an arrangement similar to that used in experiment 9 was installed at the packing house of the Whittier Citrus Association. The pipe was extended from the first of a series of four sweat rooms, across the two middle rooms, and into the fourth. The room, which was large enough to hold about a carload, was filled with fruit from different orchards and the lemons consequently varied largely as regards color and roughness. Temperature readings were taken every few hours, and, although the adjoining room was heated, the maximum temperature observed was 77° F. A few fires were placed under the fruit during the last days of the experiment, mainly because the management desired to dry the boxes, which had become quite wet from the moisture carried over. The color obtained was satisfactory in every way and was developed in eight days.

POSSIBILITY OF USING GASEOUS PRODUCTS ON A COMMERCIAL SCALE.

The experiments regarding the feasibility of piping combustion products of stoves over considerable distances without destroying their effectiveness in coloring lemons have given results sufficient to warrant the assumption that this process can be utilized to advantage in coloring large lots of fruit. It is true that the experiments have been made mostly with but small quantities of fruit in the sweat room, but repeated observations in many different packing houses have shown that a room which is full of fruit will give quicker and better results than a room only partially filled. Should this opinion be well founded, success under these circumstances would indicate even better results when the room is filled with fruit. The explanation perhaps lies in the fact that there is a more favorable concentration of the gases if a small volume of air is present. It is quite possible, therefore, that if the room which was used in experiments 8 and 9 had been filled with fruit the results would have been better.

In making use of these gases for the purpose of coloring lemons the question naturally arises whether there may not be some better means of producing them than the burning of distillate. In order to determine this question it is, of course, necessary to establish definitely the exact composition of these gases and to what particular constituent or group of constituents the desired action is due. That these combustion products form a highly complex mixture is hardly to be doubted, and whether it is the action of a single constituent or the combined action of several is a question which must remain for the present unanswered. No adequate facilities for making an examination of the combustion products were at hand during these investigations. Granted, however, that it can be determined just what gas or gases are effective, the question still remains whether they could be manufactured more cheaply and applied more conveniently than when produced by the stoves. As stated before, one of the chief objections to the stoves, especially where the sweat rooms are in the packing house, is the possibility of fire. This objection could be eliminated by constructing a cellar of stone or concrete, or simply by making excavations in which to keep the stoves some distance from the buildings. The gases could here be generated and piped to the various sweat rooms through a distribution system. Under the present system much of the pungent gas is lost by leakage through the walls of the rooms, as is evidenced by the presence of these pungent odors in the atmosphere surrounding such sweat rooms when in operation. With a careful construction of the rooms containing the fruit and of the generating room, and the consequent decrease of leakage, less gas would need

to be generated, thereby causing a saving of fuel. Another distinct advantage would lie in the fact that it would not be necessary to regulate the temperature, the fruit being sufficiently distant not to be affected by the heat generated. This would enable the operator to use his stoves under such conditions as would give the largest amount of these combustion products. In the present sweat rooms the stoves must above all else be regulated so as to give the proper temperature and not give a smoky flame. Thus the generation of gases must necessarily become a secondary matter. Probably it is largely for this reason that such a lack of uniformity exists in the results derived from forced curing. There is at present little precise information at hand concerning the effective gaseous products, and further investigations are required before many of the practical questions concerning the use of these products can be answered. It is not known, for example, what concentration of gases gives most favorable results or what effects on color and keeping quality follow the use of too great or too dilute concentrations. It remains to be ascertained how long these gases will remain effective in the sweat room and whether ventilation is helpful or necessary. These and many other questions are at present unanswered.

INFLUENCE OF VENTILATION AND CONSTRUCTION MATERIALS OF THE SWEAT ROOM ON THE COLORING OF LEMONS.

Mention has already been made of the influence which the materials employed in the construction of the sweat room exert on the coloring of lemons. Special attention has been directed to the fact that rooms having concrete walls give better results than those having wooden walls. As it was considered possible that the concrete walls might have some influence, aside from being merely well adapted mechanically for preventing the escape of heat and gases, a series of experiments was made, designed to show the extent to which ventilation and absorbing surfaces affect the coloring of the lemons.

Experiment 11.

In experiment 11 three wooden boxes (A, B, C), large enough to hold about three boxes of fruit, were filled with "light" dark-green fruit. Box A was kept tightly closed during the time of the experiment, so that all the respiration products from the fruit would remain in the box. Box B was opened daily and ventilated. In box C were placed some charcoal to absorb gases and some calcium chlorid to take up excessive moisture. This box was kept closed. Table III shows the results of the experiment.

TABLE III.—*Effect of ventilation and absorbents on the coloring of lemons.*

Box.	Treatment.	Progress in the coloring of the fruit.			
		First week.	Second week.	Third week.	Fourth week.
A	Closed	No apparent change.	Very slight change.	Coloring fairly well.	Some colored; others still green; uneven.
B	Ventilated daily	do	do	do	Fully covered and very even.
C	Closed, with charcoal and calcium chlorid.	Considerably colored.	Slightly advanced over first week.	Fully colored. Color very complete, but not of best appearance.	

EXPERIMENT 12.

In experiment 12 box C was lined with bricks. In box B were placed 2 inches of loose earth, and box A was used as a check. The fruit, which was of the "light" dark-green shade, was placed in the boxes on October 27, and on November 22 was taken out, with the results shown in Table IV.

TABLE IV.—*Effect of the use of absorbents alone on the coloring of lemons.*

Box.	Treatment.	Condition of fruit.
A	Check	Considerably colored, but not enough to grade.
B	Loose earth on bottom	Fully and perfectly colored.
C	Lined with bricks	Do.

CORROBORATIVE OBSERVATIONS.

Experiments 11 and 12 seem to show that material of a porous nature like bricks, concrete, or earth has a tendency to facilitate coloring, an action difficult to explain. The results, however, are in line with observations made in various localities. In a recently constructed sweat room in which the walls were of sheet iron unsatisfactory results were obtained, which may have been due, in part at least, to the use of this material. In another locality it was found that a room constructed entirely of concrete gave much better results than an adjoining room which had only a concrete basement, but in which the desired temperature could be readily maintained. It has also been noticed that in a room having two outside concrete walls and two wooden partitions fruit stacked along the concrete walls colors somewhat more rapidly than that near the wooden partitions. Earth, being more porous than most other materials suitable for construction purposes, would possibly give the best results.

LOSS OF STEMS.

One of the most serious defects of the sweating process is its tendency to loosen the stems of the fruit. In the curing process these stems usually remain on the lemons in a firm, green condition, but the treatment in the sweat rooms results in the loss of a large per-

centage. From evidence at hand, however, it seems that the absence of the stems affects the value of the fruit chiefly through the effect on its appearance.

INFLUENCE OF HUMIDITY.

The causes leading to the loss of the stems from lemons during the sweating process are not well understood and a number of explanations have been offered. The most generally accepted explanation is that the stems are loosened by the excessive humidity in the sweat room. Much evidence may be found in support of this theory. The stems, as they break loose from the lemons, have the appearance of having been forced loose by the swelling of the pulpy tissues at the base of the stem through excessive absorption of water. As the heat and humidity of the sweat room are so radically different from that in the tents, it has seemed natural to assume that either one or both of these factors are instrumental in causing the stem to loosen. Furthermore, whenever fruit in tent curing undergoes a sweat the stems are liable to be lost. In such cases considerable quantities of moisture are often found to have accumulated on the lemons, and this condition may be assumed to have a causal relation to the loss of stems.

In view of such evidence as has come to the writers' attention, other factors besides humidity seem to influence this result. The loss of stems seems to be greatest in cases where the fruit colors rapidly. In lots requiring from 10 days to 2 weeks to produce the desired color the dropping of the stems is considerably less than when the coloring takes place more rapidly, even though the conditions of temperature and humidity in the two sets of conditions seem to be approximately alike. It is observed that as long as the lemons remain green there are no signs of the loosening of the stems, but when the change of color begins to take place, especially if this happens rapidly, the loosening begins to be noticeable. This would seem to indicate that other factors than those mentioned play a rôle in this matter.

In order to obtain more information as to the cause of the loss of stems, a number of experiments were made having for their object the determination of the part played by humidity and the nature of other possible influences. It was considered feasible to combine this work with the experiments on coloring which have already been described. Reference will therefore be made to the experiments as designated in that chapter.

EXPERIMENT 3.

By reference to this experiment it will be found that the humidity in box 1 was kept normal, while in box 2 it was very high. In both boxes all the stems were off. As has been stated above, the humidity and temperature in box 1 were very nearly like that in a curing tent. Here, then, we have a total loss of stems under practically tent conditions of heat and humidity.

EXPERIMENT 4.

This experiment was conducted in a manner similar to the preceding. In this case again all the stems were off in both boxes.

EXPERIMENT 5.

This was another duplicate of experiment 3. Again the same condition of stems prevailed. In all three experiments it was noticed that although in box 1 the stems were either off entirely or so loose that they could be brushed off with a touch of the finger, they were much less puffy than those in box 2. Evidently the spongy tissues of the stems could not absorb as much moisture as is usually the case, owing to a lower humidity, and hence appeared drier. On the other hand, those in box 2 were much swollen and the swollen tissues had a mushy appearance. It can be seen, therefore, that it is not the absorption of water by the stem tissues when in a highly humid atmosphere that causes the loosening of the stems. Neither can it be the action of heat or the combined action of heat and humidity, for heat also was absent in this case. We have, then, a total loss of stems under a treatment consisting only of an application of the gaseous products from the stoves.

EXPERIMENT 6.

In experiment 6 the opposite condition existed. All combustion products were withheld, but the sweat-room conditions of temperature and humidity prevailed. Under this treatment the stems remained firm on the fruit after 18 days. The fruit also remained green.

EXPERIMENT 7.

In this experiment the fruit was subjected to the above treatment for 24 days, and still the stems remained firm. When this fruit was taken out some of the lemons were lying in an inch of water on the bottom of the box. A thin skin of mold had grown over a number of them, and upon its removal the lemons were found to be very green and with firm stems. No marked absorption of water by the stem tissues had taken place, although the conditions for such action were far more favorable than in the sweat room. Part of the lemons used in this experiment were placed in a regular sweat room, and in 24 hours a decided change in color was noticeable, accompanied by a total loss of stems.

INFLUENCE OF FACTORS OTHER THAN HUMIDITY.

The results of these experiments seem to show that other factors than humidity play an important part in the loss of stems. They not only indicate clearly that an elimination of humidity will not prevent the stems from loosening, but they show equally well that if those factors which color fruit rapidly are withheld, the continued

application of heat and humidity will not necessarily cause the stems to loosen. Thus they indicate a striking relationship between the coloring of the lemons and the loss of stems. The rapidity of the former change to a considerable degree measures the extent of the latter. This view is corroborated by practical observations in operating sweat rooms.

It must not be understood that humidity has no influence whatever in this matter. There is little doubt that excessive moisture has a tendency to remove the stems, at least under certain conditions. It is equally certain, however, that humidity is not the controlling factor in this problem and that to remedy the situation changes are required which must extend farther than a simple manipulation of the humidity. Indeed, from the apparently close connection between the coloring of the lemons and the loss of stems the finding of a way to save the stems without sacrificing time in coloring seems likely to be difficult.

Table V shows the results of the experiments.

TABLE V.—*Experimental results indicating the relation of the loss of stems to the coloring of lemons.*

Box and No. of experiment.	Type of fruit.	Treatment.	Days treated.	Results.	
				Color.	Stems.
Box 1:					
1	Dark green, fairly smooth.	Gas and moisture (pumped).	5½	Good yellow (91.3 per cent).	All off; very puffy.
2	Dark green, rough.	do	7	Good, soft	Do.
3	do	Gas alone (pumped)	7	Good; small percentage green.	All loose, but dry.
4	Very dark green	do	10	do	Do.
5	Dark green	do	9	Very good; color soft and waxy.	Do.
6	do	Heat and moisture only.	18	Absolutely green	Firm.
7	do	do	24	do	Do.
Box 2:					
1	Dark green, fairly smooth.	Gas with heat and moisture (pumped).	5½	Fair (80.9 per cent)	All off; very puffy.
2	Dark green, rough.	do	7	Good	Do.
3	do	Gas and moisture (pumped).	7	Good; small percentage green.	All off and puffy.
4	Very dark green	do	10	do	Do.
5	Dark green	do	9	do	Do.
Box 3:					
1	Dark green, fairly smooth.	Gas and moisture (natural draft).	5½	Good (92.9 per cent)	All off.
2	Dark green, rough.	do	7	Fair	Do.
Box A:					
11	"Light" dark green.	Closed	28	Some well colored; others yellow; very uneven.	Firm.
12	do	Closed (check)	26	Not colored enough to grade.	Do.
Box B.					
11	do	Ventilated daily	28	Well and evenly colored.	Do.
12	do	Closed; loose earth on bottom.	26	Fully and perfectly colored.	Do.
Box C:					
11	do	Closed; charcoal and calcium chlorid.	28	Evenly colored	Do.
12	do	Closed; lined with bricks.	26	Fully and perfectly colored.	Do.

SUMMARY.

The forced curing or sweating of lemons as at present practiced consists in subjecting the green fruit to heat and humidity in closely confined inclosures until the desired yellow color is produced, the time required ranging from 5 to 14 days. Different methods of supplying the heat are used with varying success.

Experiments here described show that heat and humidity are of minor importance in coloring lemons and that the pungent, gaseous combustion products given off by the oil stoves used produce the desired effect. These gaseous products can be conducted to distant rooms by means of pipes, their effectiveness being thereby unimpaired. This suggests the possibility, in using these gases on a commercial scale, of generating them with the burners in separate structures and distributing them to different rooms containing the fruit. A great reduction of fire risk would result from such an adaptation.

The coloring of lemons is noticeably hastened when confined in spaces constructed of materials of a porous nature. Sweat rooms constructed of earth, brick, or concrete are more effective than those made of wood.

A common result of the sweating process is the loss of the stems from the fruit. This loss is supposed to provide an avenue for the entrance of organisms into the fruit, causing decay, a conclusion not justified by the available evidence. It has been generally held that excessive humidity in the sweat room causes the stems to loosen. Experiments indicate that the gaseous products applied alone will cause the stems to drop and that humidity and heat are less important factors.

It must be understood that the results recorded in this publication are put forth rather as a report of progress than as a finished investigation. It is recognized that further work is required in order to apply the results already obtained to the practical use of the lemon producer and plans for such further work are already made.

NOTE.—Since the manuscript of this bulletin left the hands of the writers, an interesting development from the investigation here reported has been worked out by certain California lemon handlers. Instead of getting the effective combustion products from the rather objectionable oil stoves, these handlers have made use of the exhaust products of gasoline-burning motors. These motors supply the heat needed for the combustion and the energy required for forcing the gases to those parts of the lemon houses in which they are needed. It is probable, however, that this method will prove rather expensive unless the energy developed can be successfully utilized in running washers, graders, or other machinery of the packing house.

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